circuit, electric

An electric circuit comprises interconnected electrical components forming a complete path for an electric current, which is a flow of electric charge. The ELECTRICITY often is used to produce a different form of energy such as light, heat, or sound.

PARTS OF A CIRCUIT

Most electric circuits have four main parts: (1) a source of electric energy such as a chemical BATTERY, GENERATOR, or SOLAR CELL; (2) a load, or output device, such as a lamp, motor, or loudspeaker; (3) conductors, such as copper or aluminum wire, to transport the electrical energy from the source to the load; and (4) a control device, such as a RELAY, SWITCH, or thermostat, to control the flow of energy to the load.

The source, which may be either DC (DIRECT CURRENT, which does not vary in direction) or AC (ALTERNATING CURRENT, which periodically reverses its direction) applies an ELECTROMOTIVE FORCE (emf) to the circuit. This emf is measured in units of VOLTS (V) and is analogous to pressure. It determines how much current (measured in AMPERES) will flow in a given circuit. The typical supply voltage in the United States and Canada is 120 or 240 volts at a frequency of 60 hertz (1 Hz = 1 cycle/sec).

Circuits may be broadly divided into four types: series, parallel, series-parallel, and complex circuits. They may be supplied from a DC or AC source.

DC CIRCUITS

Series Circuit

A series circuit is one in which the current has only one path to take--from one side of the source, through the load, and back to the other side of the source. In a circuit with metallic conductors, this current comprises the very slow drift of ELECTRONS moving from the negative side of the source toward the positive side of the source. In some semiconductor devices, such as transistors and semiconductor diodes, positive CHARGES also move in the opposite direction. This coincides with what is known as the conventional current, which is a current that is assumed to flow from positive to negative.

A flashlight is an example of a series circuit and is one of the most simple DC circuits. In order to represent such a circuit, a pictorial diagram, which involves drawings that are similar to the physical appearance of the components, may be used. A method that is preferred by electricians and technicians is to use a SCHEMATIC DIAGRAM comprising interconnected symbols, with each symbol representing an electrical component.

The source in a flashlight is two series-connected dry cells, each having an emf of 1.5 V to supply 3 V to the circuit. A 3-V bulb is the load, and a slide switch is connected between source and load. The conducting path in this case is supplied by the metallic case of the tube holding the dry cells, or batteries. When the switch is open, no current flows and the lamp is off. When the switch is closed, a complete path exists and current flows through the circuit, lighting the lamp. The current heats the filament of the lamp to a white-hot incandescence, and in this state the lamp emits light as well as heat.

If the current flowing in such a circuit is measured by connecting an AMMETER in series with the lamp, the resistance of the hot filament can be calculated by using OHM'S LAW. This law is an equation that relates the three quantities in a DC electric circuit: voltage (E in volts), current (I in amperes), and resistance (R in ohms).

Ohm's law may be written in the three equivalent forms: $E = IR$, $I = E/R$, or $R = E/I$. For example, if the flashlight current is 0.1 A from a source of 3 V, the resistance of the lamp R will be 30 ohms (commonly designated by the Greek upper-case letter omega). The voltage could be measured by a VOLTMETER connected across the two cells. The resistance of the lamp could be measured when the switch is open by connecting an ohmmeter across the lamp; this value is called the cold resistance and is found to be much less than 30 ohms, because the resistance increases considerably when the filament is at a high temperature.

Another common example of a series circuit is the series string of Christmas tree lights. The disadvantage of such an arrangement is that if one lamp burns out, the electrical path is broken and all the other lights go out. A better arrangement is a lamp that, when it burns out, becomes a short circuit; that is, it offers zero resistance to a current. With such a lamp, the rest of the lamps remain lighted. Because of KIRCHHOFF'S LAW, however, all the

remaining lamps will now have more voltage across them, and more current will flow in the whole circuit. This is so because, by Kirchhoff's voltage law, the sum of the voltage drops around any complete circuit must equal the applied emf. When Ohm's law is applied to a series circuit, R is the total resistance of all the series RESISTORS. The total power consumed in such a circuit is the sum of the individual powers expended in each lamp.

Parallel Circuit

A parallel circuit is characterized by all the loads working at the same voltage as the source and independently of one another. That is, if one load is switched off, the remainder are unaffected. The electrical system in an automobile is an example of a DC parallel circuit in which the 12-V voltage from the battery simultaneously supplies electrical energy for the ignition system, headlights, taillights, radio, and air conditioner.

If another load is added in a parallel system, it supplies another path for the current, so that the total current from the source increases. This is an application of Kirchhoff's current law, which states that the sum of the currents entering any point in a circuit equals the sum of the currents leaving that point. The combined resistance of the parallel circuit effectively decreases whenever another resistor is added in parallel. Just as in a series circuit, in a parallel circuit the total power is the sum of the individual powers.

Series-Parallel Circuit

Series-parallel circuits are those that can be identified as having some components in parallel with each other, where the parallel combinations are in series with other components. Connecting a switch and fuse or circuit breaker in series with a source and a number of parallel-connected components constitutes such a circuit.

Complex Circuits

A complex circuit is one that cannot be broken down into sections of pure series or pure parallel combinations. A WHEATSTONE BRIDGE, a circuit useful in measuring a resistance, is a good example. Basically, it comprises four interconnected resistors forming the four sides of a square. A voltage source is connected across one set of diagonally opposite corners, and a GALVANOMETER, which has a certain known resistance, is connected across the other set of corners. Only when the bridge circuit is balanced, that is, only when there is no current through the galvanometer, is the circuit a series-parallel combination. Special techniques are needed to analyze such a circuit in order to find the total resistance.

It is possible to have INDUCTORS and CAPACITORS in DC circuits, such as in an ignition system of an automobile or a photoflash system in a camera. In such applications it is the transient, or temporary, response that is important, since with respect to DC a capacitor represents an open circuit (under steady-state conditions), and an inductor has no effect unless the current through it is varying. The effects of INDUCTANCE and CAPACITANCE, however, are much more significant in AC circuits, since with AC the voltage and current are always changing.

AC CIRCUITS

Communications equipment, such as receivers and transmitters for radio and television, relies upon the behavior of series and parallel circuits that have resistance (R), inductance (L), and capacitance (C), when connected to AC. A circuit containing R, L, and C is called an RLC circuit.

A series RLC circuit will have the same current flowing through all the components. If the voltage across the resistor is observed on an OSCILLOSCOPE, a measuring instrument that shows a picture on a screen of how the voltage is varying, it will be found to have the same shape and time relationship as the current; that is, both the current and the voltage will reach a peak at the same instant and will be zero at the same instant. For such a case, they are said to be in phase with each other. The voltage across the inductor, however, is a quarter of a cycle ahead of the current and is said to lead the current by a phase angle of 90 deg. This is because the voltage depends upon the way the current through the inductor is changing. The opposition to current flow supplied by an inductor is called its inductive reactance and is given by the formula X(L) = 2pfL, where X(L) is in ohms if f, the frequency, is in hertz and L, the inductance, is in henrys.

Conversely, the voltage across the capacitor lags behind the current by 90 deg, because current only flows into or out of a capacitor when the voltage across the capacitor is changing. The opposition to current flow offered by the capacitor is given by the formula X(C) = 1/2nfc, where X(C) is the capacitive reactance, which will be in ohms if f is in hertz and C is the capacitance in farads.

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The voltages across the inductor and capacitor are 180 deg out of phase, which means that one is at its maximum positive value when the other is at its maximum negative value. If the AC source, which may be an incoming radio signal, has a frequency of the correct value, then the inductor and capacitor voltages can be equal and cancel each other. This means that their oppositions to current flow also cancel and the IMPEDANCE of the circuit (the total opposition to current), which in this case is given by Z = R(2) + X(L) - X(C)(2), is a minimum and equal to R. As a result, a large current can flow in this circuit because only the resistance is opposed current. This condition is called series resonance. At this frequency a very large voltage can occur across both capacitor and inductor. It is this voltage that is amplified, or made larger, and used to generate the sound or picture. The circuit will respond to a range of frequencies, called its bandwidth, which must be wide enough to receive all the information being transmitted. Frequencies beyond this range, however, from adjacent stations, will not be picked up because the circuit will not resonate and therefore will not produce high enough voltages. Thus the series RLC circuit is said to be selective to a certain band of frequencies. By making either the inductor or capacitor variable it is possible to tune the circuit to any desired resonant frequency and receive a particular radio or TV station.

A condition of resonance may also be produced in a parallel RLC circuit in which all the components have the same voltage across them but each has its own current. At a frequency given by the same equation as that for series resonance, a large current can circulate between the capacitor and inductor in what is called a tank circuit. This can make the circuit sensitive to only a certain band of frequencies, and the circuit can be used in tuned amplifiers in radio and television receivers.

Parallel AC circuits are found in the home, where the loads are primarily resistive; that is, the loads behave as resistors (for example, lamps, stove elements, toasters, and irons). Such loads as fluorescent lamps and motors in refrigerators and in furnaces are a combination of resistance and inductance. In industry, the load will most likely be predominantly inductive because of the large number of induction motors used. This can cause a problem to the power company because the current will be out of phase with the voltage, causing what is called a lagging power factor. This essentially is determined by the amount of inductive reactance as compared to the amount of resistance.

The result of this lagging power factor is that, to deliver a given amount of power, a larger amount of current must be supplied (using larger wires) than would be the case if the current and voltage were in phase with each other. Because this can be costly, a factory may be penalized for its poor power factor, and steps are taken to correct it. This is done by connecting large banks of capacitors in parallel with the inductive load at the factory. This effectively produces a condition of parallel resonance in which the total current necessary to deliver the same power can be significantly reduced. This is called power-factor correction and involves the transfer of some energy back and forth between the capacitors and inductors instead of the source having to supply additional energy.

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